The Role of Salinity in Structuring the Aquatic Macroinvertebrate Community of a Puget Sound Oligohaline Lagoon

Ann G. Boeholt
University of Washington, School of Aquatic and Fisheries Sciences

Abstract

The Foulweather Bluff Preserve Lagoon (FBPL), on Washington's Kitsap Peninsula, is recognized as a biologically significant site due to its historical brackish character. There is no question that saline waters, in general, influence biology. The salinity of the lagoon, however, is very near the saline water-freshwater threshold as arbitrarily defined by the Venice System (0.5 ppt), highlighting the significance of the question, does salinity have a significant influence on the biota, specifically, the aquatic macroinvertebrates of this oligohaline lagoon?

Two macroinvertebrate collection methods were employed from August 1999 to October 2000 within the FBPL, one freshwater lake, and two additional brackish lagoons (with maximum salinity values of 30.0 and 16.5 ppt). Measurements of water chemistry were taken at the time of invertebrate collections.

Laboratory analysis of macroinvertebrates collected thus far indicates that the FBPL has characteristics of a freshwater marsh. However, this analysis has also revealed an abundance of the hydra *Chlorohydra viridissima* within the FBPL. Hydras have among the narrowest ranges of salinity tolerance of all invertebrates. Among the other three sites, *C. viridissima* has been found only in the freshwater site, but at low numbers. Biological requirements of this hydra suggest that it is the low and specific level of salinity that is allowing this population to flourish in the FBPL. Further analysis will determine whether this and other invertebrate distributions are a reflection of salinity, as opposed to some other physical factor or combination of factors.

This information will serve as baseline information for The Nature Conservancy as they endeavor to preserve the FBPL, and as information for land use and environmental planners in their efforts to balance land uses and aquatic resources.

Introduction

This study has two principle objectives: to provide a baseline inventory of the aquatic macroinvertebrate fauna within the FBPL and to address the question of the role of salinity in structuring the observed aquatic macroinvertebrate fauna. Addressing the second objective has led to a review of the delimitation between fresh and saline waters within shoreline habitats of the Puget Sound region.

The FBPL lies within a 37.6-hectare preserve owned and managed by The Nature Conservancy. The brackish lagoon has approximately 8.9 hectares of standing water. It is separated from Hood Canal by a shallow sand and gravel berm. The lagoon is recognized as being one of the highest-quality, most diverse brackish lagoons in the Puget Trough region (Kunze 1984). The most complete, recent description of the lagoon states that its salinity ranges from 4.5 to 21 parts per thousand (ppt) (Cornelius 1983). This has led to the public perception that the lagoon's high preservation value is due to a mixohaline salinity regime.

The FBPL formed as net longshore drift carried sand and gravel northwesterly along the beach, forming at first a spit, and then an isolated lagoon. As recently as 1860, the berm may have been incomplete; the 1860 Land Survey field notes refer to this as a sand spit, rather than a berm (Cornelius 1983). From 1998 to the present, small flumes of marine waters have been observed to overtop the berm and to flow into the lagoon

during the winter months. Large scale overtopping and berm breaching, however, has occurred infrequently. The last berm-breaching event occurred in December 1992 (Cornelius 1983) and resulted in the above referenced salinity regime currently appearing in the literature. Long time local property owners do not recall a previous berm-breaching event in the 41 years preceding the 1992 event (Cornelius 1983).

Contrary to the published FBPL salinity regime, observations from April 1998 to October 2000, found the salinity of the FBPL to fall between 0 and 4.0 ppt and to average 0.7 ppt, placing this water body squarely within the lowest classification of brackish waters: oligohaline (0.5 to 5.0 ppt).

Different classification methods and different researchers worldwide have placed the threshold between fresh and saline waters variously from 0.1 to 5.0-ppt. salinity, depending upon the salinity level at which a response was observed in the biological communities of interest (Segerstråle 1959; den Hartog 1974; Hart and others 1991; Williams 1991). When based on biocoenoses, the saline water-freshwater threshold varies with climate, hydrography, and habitat. Regulations and guidance materials published by Washington State (Washington State Department of Ecology 1993; Washington Administrative Code 173-22-030) and United States natural resource agencies (Cowardin and others 1979) generally cite 0.5 ppt salinity as the partition between fresh and saline (or estuarine) waters, according to the popular Venice System. This determination is arbitrary, however, and does not consider the specific tolerances of regional biota to low levels of salinity.

The average salinity within the FBPL (0.7 ppt) falls at the point that salinity levels were found to be biologically significant in other studies (according to Hart and others 1991, adverse effects are apparent for some insect species at salinities as low as 1 ppt). Given that the FBPL would be described as fresh by some classification methods, but yet has trace amounts of marine-derived salts, the question is raised of whether the salinity is having a significant (noticeable) effect on the macroinvertebrate fauna within the lagoon. Other ways to ask this question are, what salinity level delimits fresh from brackish waters in the Puget Sound region, or, at what salinity level is the biocoenoses of Puget Sound coastal lagoons affected?

Objectives

Attributes of the aquatic macroinvertebrate communities of four sites, representing a range of salinity values, are being compared to determine if salinity is having a significant role in structuring the aquatic macroinvertebrate communities or if any salinity affect is overshadowed by other environmental factors.

Methods

Aquatic macroinvertebrates were collected from four sites from September 1999 to October 2000. The sites selected are relatively proximate to one another and share as many common physical features as could be found while providing a range of salinity values (Table 1). All sites have between 8.9 and 18.6 hectares of standing water and, with the exception of Buck Lake, are all less than 2 m deep. They all have fringes of emergent vegetation, and while some of the sites have common species of vegetation, the overall vegetation communities differ from site to site.

Table 1. Physical and chemical characteristics of research sites.

Site	Latitude	Longitude	Altitude (m above msl)	Surface area (hectares)	Max Depth (m)	Mean Temp (C)	Mean pH	Mean DO (mg/L)	Mean Salinity (ppt)	Mean Conductivity (mmhos/cm)
Buck Lake	47.91	122.56	42.57	8.9	7.32	14.5	7.4	9.6	0	0.1
FBP Lagoon	47.92	122.60	2	11.3	0.92	16.4	7.2	9.2	0.7	1.9
Kah Tai Lagoon	48.11	122.78	0.6	18.6	0.92	15.9	7.4	10.2	10.9	18.6
Chinese Gardens	48.14	122.78	0.1	18.2	0.93	17.3	7.7	10.3	25.5	39.9

In selecting the freshwater "control" site, a lake close to marine waters was considered to reduce the chance that colonization opportunity could be responsible for any differences in the macroinvertebrate communities. Buck Lake is less than 3.2 kilometers from the FBPL and within 0.8 kilometers of salt water.

The FBPL was the primary research site and was sampled monthly from August to October 1999 and March to September 2000. Secondary sites were Kah Tai Lagoon and Chinese Gardens Lagoon, within the City of Port Townsend, and Buck Lake (a freshwater lake), within the town of Hansville. The secondary sites were sampled quarterly: in April, July, and October 2000. Buck Lake was also sampled in October 1999.

Samples were randomly stratified with respect to dominant vegetation communities (including open water). Two stations were randomly selected per vegetation community, within each site, for each sampling event. Stations did not remain the same from one sampling event to the next. Within the FBPL, stations were further stratified per transect: two permanent transects were established parallel to the berm (perpendicular to the salinity gradient observed by Cornelius, 1983) and two stations per vegetation community (one east and one west of the transect midline) were randomly selected along each of the two transects during each sampling event.

Two sampling techniques were employed at each station: an aquatic sweep net and an invertebrate activity trap (Hanson and Swanson 1989; Solberg and Higgins 1993; Turner and Trexler 1997; Linz and others 1999). The activity traps work better than the sweep net in dense vegetation; however, they are biased in that they trap only those macroinvertebrates that have occasion to swim into them. Also, they may favor more predatory invertebrates than is truly representative of the community, as they trap and hold "bait" that may attract and feed the predators. The activity traps were constructed of two plastic soda bottles, the top cut from one and inserted into the cut-out bottom of the other, forming a funnel directed inward. The sweep net (800 x 900 micron multifilament nylon) has its own inadequacies: larger mesh size, difficult to use consistently in dense emergent vegetation, may under-represent fast swimming invertebrates, does not account for diel shifts in horizontal and vertical distribution (Murkin and others 1983). Turner and Trexler (1997) suggested that these two sampling methods make a good complement when sampling for aquatic macroinvertebrates in marshes: each compensates, somewhat, for the biases inherent with the other.

Activity traps were attached to PVC stakes and held horizontally immediately below the water surface. In a few instances, when the water level was very low, the trap opening was not completely submerged. The traps were emptied after approximately 24 hours. The sweep net was employed at each station before or after retrieving the activity trap, and following the measuring of water quality parameters with the Hydrolab.

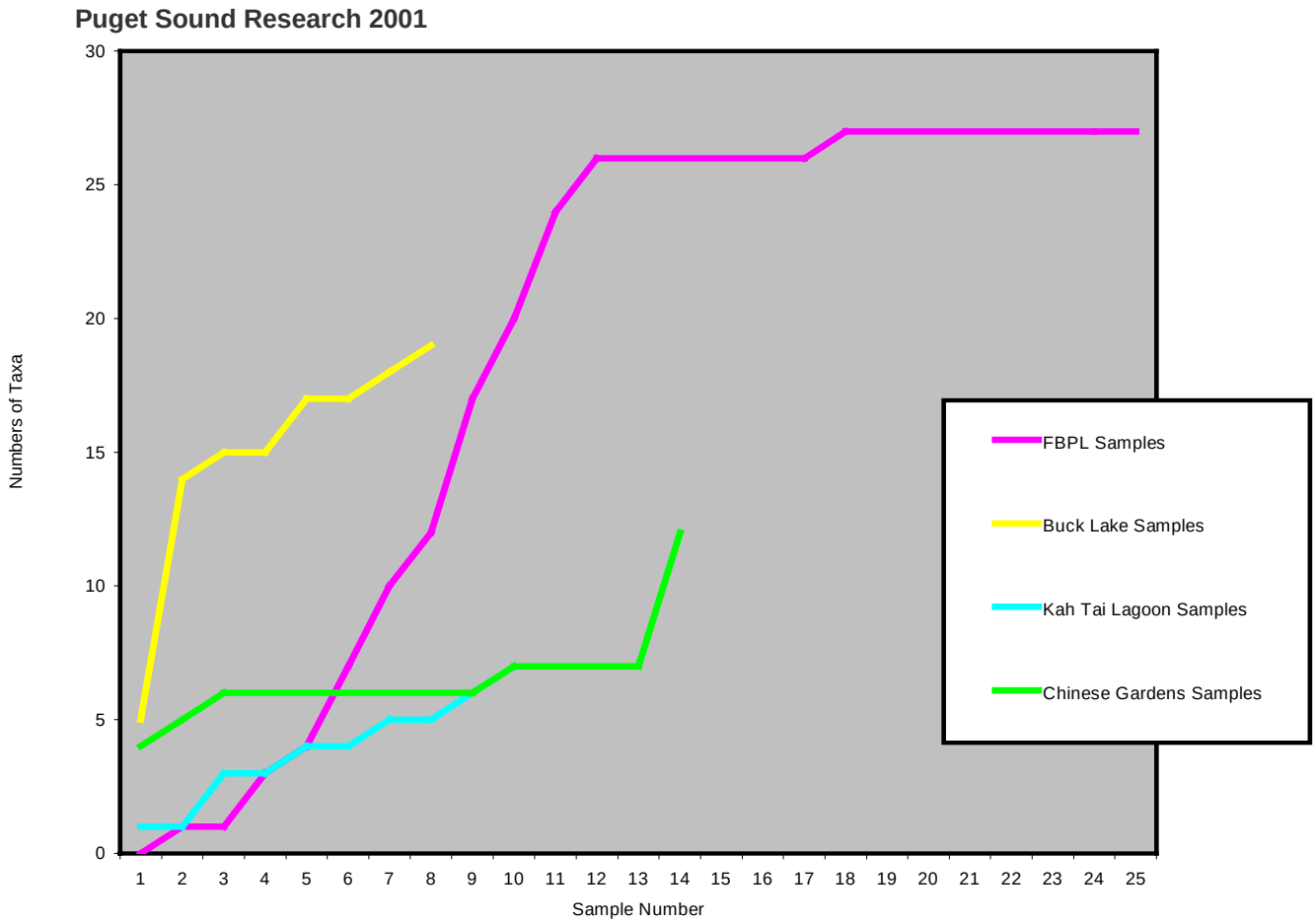

Figure 1. Species-Area Curve of Quarterly Samples.

Samples were rinsed with filtered lagoon water through a 500-micron mesh sieve, bottled, and preserved in 75% ethanol solution. Water quality measurements of temperature, pH, dissolved oxygen, salinity, and conductivity were taken at each sample station. Water depth at each station was recorded as well.

Results

Sorting and counting macroinvertebrates continues to date. With 34 percent of the samples sorted so far, I can report some preliminary observations and emerging trends.

Pennak (1978) explained that brackish waters generally contain fewer invertebrate species than either fresh or marine waters. Yet, laboratory analysis has, so far, yielded macroinvertebrate species counts of 32 for FBPL, 31 for Buck Lake, 12 for Chinese Gardens Lagoon, and nine for Kah Tai Lagoon. Species-area curves of the quarterly samples (Figure 1) show the cumulative numbers of species per level of effort for each site. These curves reveal that species numbers are similar between Buck Lake and the FBPL and between the two more saline lagoons. The lower species numbers in the more saline sites was expected. It is with some surprise, however, to observe that the numbers of invertebrate species and the species-area curve in the FBPL resemble those from Buck Lake, the freshwater site. Although the FBPL is considered brackish, it does not appear that its complement of species follows the above rule of fewest invertebrate species in brackish waters. Consideration of macroinvertebrate species numbers alone suggests that the FBPL is more akin to a freshwater marsh than a brackish marsh.

The predominant FBPL taxa are oligochaetes (segmented worms), ostracods (seed shrimp), and chironomids (non-biting midges). Subdominant FBPL taxa are Zygoptera (damselfies), Hydracarina (water mites), copepods, and *Chlorohydra viridissima* (green hydra). Hart and others (1991) concluded, "the most

sensitive insects to increases in salinity are stoneflies, some mayflies, caddisflies, and dragonflies, and certain water-bugs." Consistent with this, stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera) have not been found within the FBPL, although stoneflies and caddisflies have been found in nearby Buck Lake. Dragonflies (Anisoptera) and water bugs (Hemiptera), however, are fairly numerous within the FBPL.

Incidental vertebrate observations generate mixed conclusions. Fish were incidentally captured in the activity traps from all sites. Bass (*Micropterus sp.*) were trapped from the emergent fringes of Buck Lake, while the three-spined stickleback (*Gasterosteus aculeatus*) was the only fish incidentally trapped or observed within the three lagoons, suggesting that the FBPL is, in fact, more similar to the other brackish lagoons. But then again, the red-legged frog *(Rana aurora)* and the northwestern salamander (*Ambystoma gracile*) were observed to have bred successfully within the FBPL. A single larva of *Ambystoma gracile*, incidentally captured in June 2000, was likely to have been hatched in 1999, based on its length of 14 cm at the time of capture (William P. Leonard, personal communication). Amphibians are generally intolerant of saline conditions and the evidence of amphibian breeding success and of a salamander larva having overwintered in the lagoon, indicate that the lagoon is not significantly saline and furthermore that salinity has not spiked between observations.

All sites have gammarid amphipods. *Parallochestes sp.,* found in both of the brackish Port Townsend Lagoons, evidently has a wide range of salinity tolerance (from an average low of 11 ppt in Kah Tai to an average high of 25 ppt in Chinese Gardens), but there is a concentration below which it apparently is intolerant. *Allochestes sp*., on the other hand, was found in Buck Lake and the least saline FBPL, seemingly in place of *Parallochestes sp*.

Mysis littoralis, a common estuarine crustacean, was anticipated to be present in both Port Townsend brackish lagoons. While the species was abundant in Kah Tai Lagoon, it was surprisingly absent from Chinese Gardens.

The green hydra, *Chlorohydra viridissima,* was found in the FBPL and Buck Lake, although it appears to be abundant only in the FBPL. Hydras have a narrow salinity tolerance and, according to Hart and others (1991), are amongst the most sensitive to salinity increases. However, they do seem to require some calcium for growth, and that can be obtained from the calcium carbonate in seawater. Loomis (1954) found that hydra has optimal growth in 5 percent seawater (about 1.5 ppt). Hart and others (1991) reported hydra in aquatic habitats with salinities ranging from 0.34 to 2.24 ppt. These salinities coincide with the range of salinity currently found with the FBPL; the stations so far found to contain hydras were within the salinity range 0.5 to 1.5 ppt.

Conclusions

The high number of taxa found within the FBPL suggests that the influence of salinity within this lagoon is not great. Other factors, primarily the abundance of hydra, suggest that there is, still, some influence. However, the influence of salinity appears to be much less significant than otherwise suggested by the published description of this site and by the observation of Hart and others (1991) that adverse effects are apparent for some insect species at salinities as low as 1 ppt. This conclusion contradicts the literature describing this preserve and advocating its preservation value.

Taxonomic richness, however, can be affected by numerous factors. Friday (1987) found that the amount of vegetated area in ponds is positively correlated with the number of invertebrate taxa. Olson and others (1995) likewise found greater numbers of invertebrate taxa associated with emergent stands of vegetation than in unvegetated areas. De Szalay and Resh (1996) found plant architecture to have a great influence on the numbers and kinds of taxa present. The FBPL substrate is unconsolidated peat. Loose peat often floated into the activity traps and ended up in those samples, introducing organisms that may have truly been benthic in nature, particularly ostracods, chironomids, and oligochaetes, which therefore may have resulted in a slight increase in number of taxa. Finally, development of the lagoon, infrequent natural perturbations,

and the subsequent pattern of invertebrate colonization and re-colonization establish competition and predation interactions (Sutherland 1974) and may have a role in determining the existing lagoon fauna.

Another explanation for the high numbers of taxa within the FBPL could be that this site is reasonably pristine. Taxonomic richness is a population metric typically attributed to aquatic sites with little human disturbance. The FBPL does have the least human disturbance, followed by Buck Lake and then the Port Townsend lagoons. It has not been possible to control for all potential factors affecting the invertebrate communities of the study sties. Nonetheless, hypotheses generated from the samples sorted so far are that taxonomic richness may be a reflection of the pristine quality of the FBPL or that the pristine quality of the FBPL counteracts the stress that brackish water places upon macroinvertebrate communities. Acceptance of either hypothesis would validate the many hours that volunteers have devoted to protecting this site. And, if lack of human disturbance is accountable for the high numbers of taxa within the FBPL, repeating the sampling of aquatic macroinvertebrates several years from now may be useful in evaluating whether protection efforts continue to pay off.

Salt-sensitivity of invertebrates is affected by the condition of the organism, the degree of acclimation, life stage, and ambient temperature. Nonetheless, this research so far suggests that it is, at least in part, the low and specific range of salinity within the FBPL, that is currently allowing the population of *Chlorohydra viridissima* to flourish there. It seems probable that increases or decreases in the salinity of the FBPL could disturb this hydra population. Laboratory salinity tolerance testing could help to resolve this question.

It is yet unclear whether 0.5 ppt is a biologically meaningful threshold between fresh and brackish waters within northern Puget Sound shoreline environments. Some evidence (i.e., the abundance of *C. viridissima* in the FBPL) suggests that it is, whereas other evidence (i.e., amphibian breeding success and numbers of taxa within the FBPL) suggest that it is not. Improved knowledge of the specific macroinvertebrate communities that are likely to be found in different ranges of salinity within brackish shoreline environments will enable ecologists to better advocate proper management and protection measures.

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References and Citations

Cornelius, L.C. 1983. Baseline Inventory of a Brackish Wetland and Berm at Foulweather Bluff Preserve, Kitsap County, Washington, March to October 1983. A report prepared under contract with the Washington Field Office of The Nature Conservancy, Seattle, Washington

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and deepwater habitats of the United States. Unites States. Fish and Wildlife Service. Biological services program; FWS/OBS-79/31.

den Hartog, C. 1974. Brackish-water classification, its development and problems. Hydrobiological Bulletin, **8**, 15-28.

de Szalay, F.A. and V.H. Resh. 1996. Spatial and temporal variability of trophic relationships among aquatic macroinvertebrates in a seasonal marsh. Wetlands, **16**(4): 458-466.

Friday, L.E., 1987. The diversity of macroinvertebrate and macrophyte communities in ponds. Freshwat. Bio. **18**:87-104.

Hanson, B.A. and Swanson, G.A. 1989. Coleoptera species inhabiting prairie wetlands of the Cottonwood Lake area, Stutsman County, North Dakota. Prairie Naturalist **21**(1):49-57

Hart, B.T., P. Bailey, R. Edwards, K. Hortle, K. James, A McMahon, C. Meredith, and K. Swadling. 1991. A review of the salt sensitivity of the Australian freshwater biota. Hydrobiologia **210**:105-144.

Kunze, L.M. 1984. Puget Trough coastal wetlands: a summary report of biologically significant sites. Report by the Wash. Dept. of Natural Resources Natural Heritage Program to the Wash. Dept. of Ecology. 154 pp. Olympia, Washington.

Linz, G.M., W.J. Bleier, J.D. Overland, and H. J. Homan, 1999. Response of invertebrates to Glyphosate-induced habitat alterations in wetlands. Wetlands, **19**(1):220-227.

Loomis, W.F. 1954. Environmental factors controlling growth in hydra. J. Exp. Zool. **126**:223-234.

Murkin, H.R., P.G. Abbott, and J.A. Kadlec. 1983. A comparison of activity traps and sweep nets for sampling nektonic invertebrates in wetlands. Freshwater Invertebrate Biology **2**:99-106.

Olson, E.J., Engstrom, E.S., Doeringsfeld, M.R., and Bellig, R. 1995. Abundance and Distribution of Macroinvertebrates in Relation to Macrophyte Communities in a Prairie Marsh, Swan Lake, Minnesota. Journal of Freshwater Ecology **10**(4): 325-335.

Pennak, R.W. 1978. Fresh-water invertebrates of the United States, Second Edition. John Wiley & Sons: New York. 803 pp.

Segerstråle, S.G. 1959. Brackishwater classification: a historical survey. Pgs 7-33 In International Association of Limnology. Symposium on the classification of brackish waters. Arch. Oceanogr. Limnol., Roma. **11** (Suppl.), 1-248.

Solberg, K. L. and Higgins, K.F. 1993. Effects of glyphosate herbicide on cattails, invertebrates, and waterfowl in South Dakota wetlands. Wildl. Soc. Bull. **21**:299-307.

Sutherland, J.P. 1974. Multiple stable points in natural communities. The American Naturalist **108**(964): 859-873.

Turner, A.M. and Trexler, J.C. 1997. Sampling aquatic invertebrates from marshes: evaluating the options. J. N. Am. Benthol. Soc., **16**(3):694-709.

Washington Administrative Code 173-22-030. Adoption of designations of shorelands and wetlands associated with shorelines of the State.

Washington State Department of Ecology. 1993. Washington State wetlands rating system for western Washington; second edition. Publication No. 93-74.

Williams, W.D. 1991. Comments on the so-called salt lakes of Greenland. Hydrobiologia **210**: 67-74.